Insight Racing Technical Paper

DARPA Grand Challenge 2005

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Abstract

Insight Racing has worked for the past three years developing autonomous vehicle technology. This team is composed of Engineers and North Carolina State University Engineering students. The vehicle systems were designed to be modular and, with little modification, can be installed in any commercial or military sport utility vehicle. The sensors mounted on the vehicle give data on both the vehicle's status, and on the surrounding environment. Based on this sensor data the master computer makes decisions directing steering, throttle, and brake control. The computer systems then control these traditional vehicle systems with motors and linear actuators

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Introduction

Two and a half years ago a team of interested participants from the Raleigh area began working on developing a vehicle for the first DARPA Grand Challenge. The team began as one engineer and four North Carolina State University engineering students. Since its inception, Insight Racing has nearly doubled in size and is now composed of three NCSU students along with six engineers. The students are from diverse fields, Mechanical, Aerospace, and Electrical Engineering. In addition to these nine team members, we have two to three senior design projects done by students in the NCSU Computer Science department each semester. Each of these projects utilizes the skills of four undergraduate computer science students to develop a different portion of the code. Some of these projects have included development of downward looking laser range finder software as well as our stereo camera image processing. Although all team members work together on the truck, each member has an area of expertise that they concentrate on. Tasks are divided amongst the members with five people doing the majority of the programming, two doing the mechanical work, one doing the electrical work and one keeping track of legal documents and fundraising.

Our team is currently continuing to develop the vehicle, learning from the past competition and working towards the 2005 race. This past January we were the first team in the nation to autonomously complete the Alpha Course at the Joint Unmanned Systems Test Experimentation and Research (JOUSTER) Site at Virginia International Raceway.

1. Vehicle Description

Our base vehicle is a 1987 Chevrolet Suburban. Our vehicle's means of mobility is four wheel drive transmitted to the ground through standard rubber truck tires. All four tires are 275/70 R16. We decided to use this vehicle because it provides us with rugged four wheel drive performance and has plenty of interior space for all our equipment. Another advantage to the Suburban is that we were able to get all of the necessary equipment behind the back seat, which allowed us to have four open seats for team members to ride inside the vehicle to debug.

2. Autonomous Operations

2.1 Processing

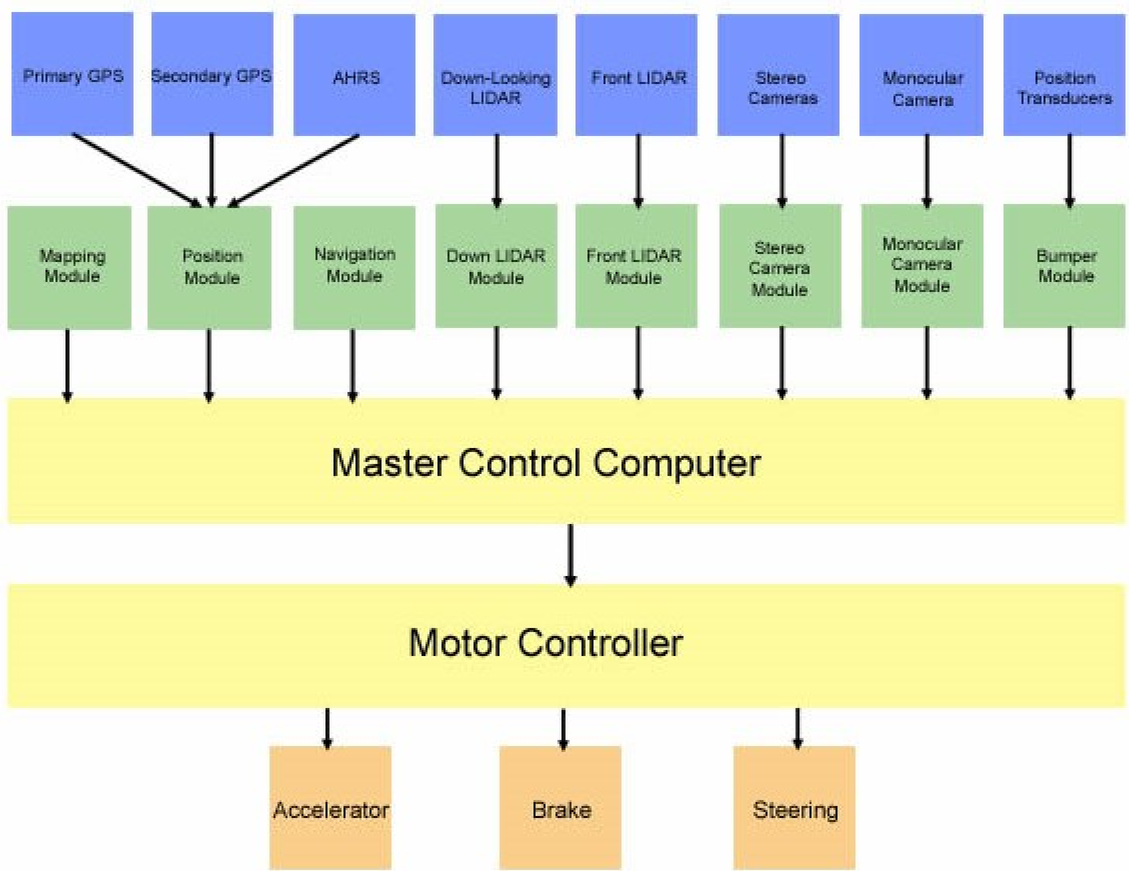
2.1.1 Computing Systems

All of the computers and electrical systems will be contained in a standard 19" server rack. The server rack will be 32" tall and have ports on the side so that wires can easily be plugged in to provide power and sensor inputs, as well as output to the motors. The rack is mounted on 4 springs, with a thick layer of foam to help dampen the motion. This spring mounted system will help isolate the computer systems from the truck vibrations and shocks. The rack could be installed in the back of any vehicle equipped with the appropriate sensors installed and be fully operational in a matter of a few hours.

Our processing power includes the use of 5 different full computers and 4 single board computers. The different processors include Intel, AMD, IBM PowerPC, and Atmel processors. Each of these different brands are used because of their different advantages and capabilities.

Once a steering direction and driving speed is determined, it is communicated through the RS-232 port to a controller, developed by BDMICRO, that regulates the actual positions of the necessary steering and speed motors using PWM signals. The outputs are sent to speed controllers, which control the actual movement of the linear actuators, which control the gas and brake pedal as well as the gear motor, which drives the steering column.

2.1.2 Processing Architecture



2.2 Localization: GPS and INS Systems

The main source of localization that is used by the position module is the GPS/INS unit. Our primary GPS is a Novatel Propak LB plusGPS. This GPS is WAAS plus Omnistar enabled, therefore it has +/- 0.1 meter accuracy. We are also using a Garmin GPS 16A, which is WAAS enabled, as a redundant source of GPS signals. Both GPS units have unique characteristics that work well under different conditions and complement each other well.

Our INS is based off a Crossbow AHRS 400 unit. We update its location using the GPS and determine our current position using the accelerations given from the device. Through integration of the given accelerations it will allow us to keep fast updating and accurate position readings. The INS will be further updated in real-time assuming GPS signal is present and at an acceptable quality. If GPS signal is lost or degraded we will continue to get our position data directly from the INS calculations and the use of dead reckoning based on truck parameters.

2.3 Sensing

2.3.1 Sensor Location and Mounting

Environment sensors on our vehicle include three cameras, AHRS (Attitude, Heading, and Reference System), two Space Age Position Transducers and also two laser radar systems.

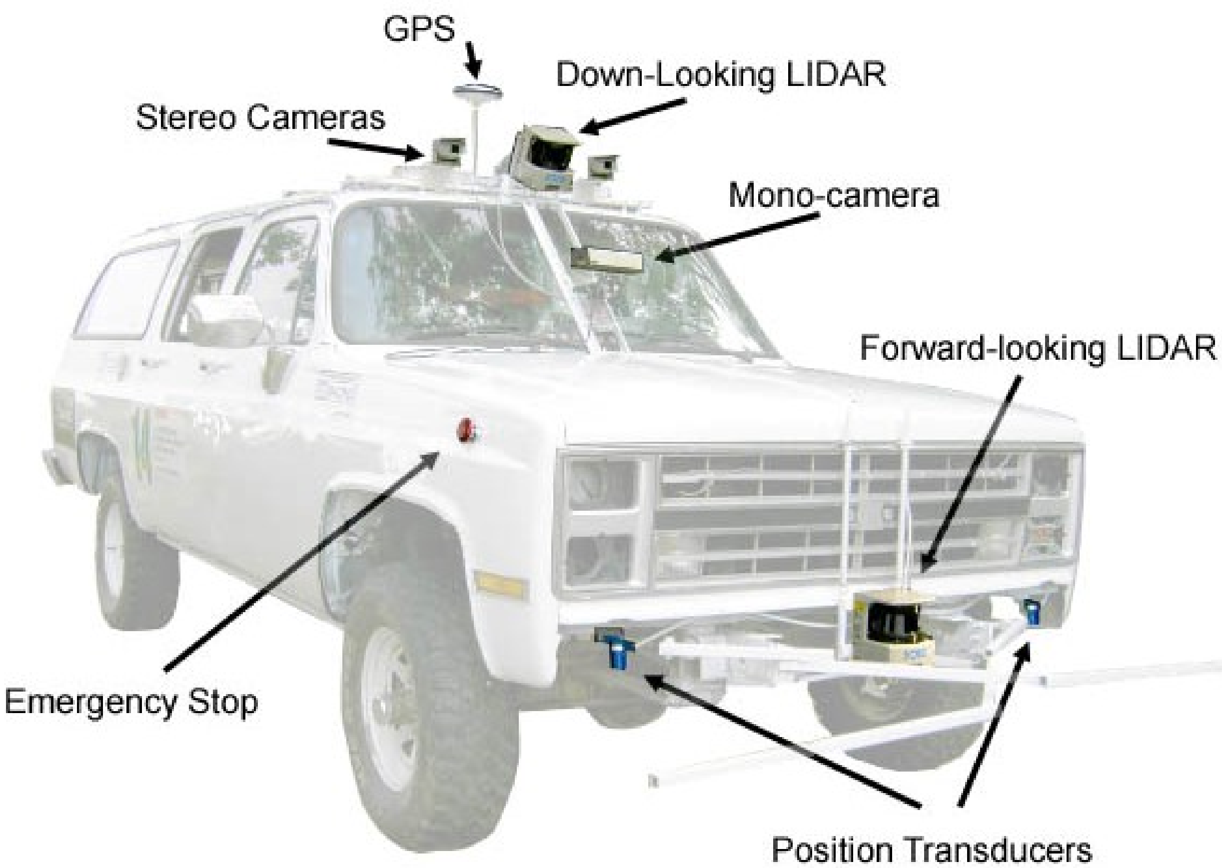
The monocular-vision camera is mounted in front of the windshield and looks in the direction that the vehicle is traveling in an attempt to avoid large objects in front of the vehicle and follow any roads or paths. It turns to the same angle the wheels are turning in order to continue to look ahead along the vehicle’s path. This helps to avoid confusion through turns.

The other two cameras are mounted on top of the vehicle on the front corners above the windshield. They act as a stereo camera system, each viewing similar images and then determining the distance and angle to each object in the vehicle’s path. This allows us to find depth of the objects in front of the vehicle using cameras.

The AHRS is used to detect accelerations in each of the three axis of movement. This acceleration data is then used to help determine how rough the road is and adjust the vehicle speed accordingly. It is mounted inside the vehicle to protect it from the elements, and as far away as possible from all large metal objects and computers to reduce interference with the magnetic heading.

The Position Transducers are attached to two spring-loaded bars on the front of the vehicle. The bars act as a retractable bumper. These sensors are used when the vehicle is blocked to determine if the object in front of the vehicle is something that should not be hit, or simply tall grass. As the bumper retracts, the position transducers begin to signal the existence of an object.

Laser Radar units will be attached to the vehicle to help determine the amount of room the vehicle can move in each direction. These will prevent us from running into other vehicles and objects. The radar units will have a range of 80 meters (ideal, 40-50 meters in normal environments) and not be affected by fog or bright lights. They will see a single plane of distances with an accuracy of +/- 35 cm. The lasers are class 1, so they are harmless for the eyes. One of these SICK LIDARs will be mounted on the front of the vehicle to look for objects in the path. The other will be mounted on top of the vehicle looking downward at an angle. This will sweep along the roadbed to find holes or rises and also determine where the edges of the road are. The angle of the downward looking SICK LIDAR is variable such that the SICK LIDAR will look further ahead of the vehicle at higher speeds.



2.3.2 Sensing Architecture

The processing of each sensor is done individually. Using the data available to that module, each sensor and its associated module summarizes the information associated with the sensor. Then our master control computer collects all of the sensor information from each module and generates a single direction and speed that is fed to the vehicle control system.

2.3.3 Internal Sensing

Multiple sensors are employed within the vehicle systems to control the motor and actuators. A potentiometer is mounted to the front of the steering sprocket. The location of this sensor will determine which direction the wheels are currently headed. There is a potentiometer located on the linear actuator that controls the shifter so that we can sense the position of that linear actuator to determine if the truck is in park, reverse, drive, or neutral. There is also a potentiometer mounted on the brake motor so we can precisely adjust the brake pedal position. Further we find the position of the accelerators linear actuator using the built in potentiometer in the throttle system in the truck. All actuators automatically disengage when they reach the end of their travel due to built in limit switches. A rotary encoder that is attached directly to the speedometer cable senses the truck’s speed.

2.3.4 Sensing-to-Actuation Systems

The steering is controlled by one gear motor, which drives a sprocket connected by chain to another sprocket mounted on the end of the steering column. The steering inputs are transmitted through a standard steering column, into a gearbox. Tie-rods extending from the gearbox connect to the spindles holding the front wheels. The brake is controlled by a wire connected through a pulley to the back of the brake pedal. The wire is then winched in around a spool that is mounted on a motor shaft. A linear actuator attached directly to the throttle body in the engine bay runs the accelerator. Another linear actuator is attached to the shifter mechanism in order to be able to autonomously put the truck into park, reverse, drive, or neutral. Speed controllers drive the gear motor and actuators from a 12V DC source. The signal is sent from the computers to the speed controllers via PWM (pulse-width modulation) wires.

2.4 Vehicle Control

2.4.1 Methods for Autonomous Operation Contingencies

The common contingencies are handled through well monitored vehicle parameters. Our software locates itself within the given course definition and determines the current waypoint through that process. Therefore, if a waypoint is missed we will continue to travel towards the course and switch to the segment we find ourselves entering. This is similar to the vehicle going out of the lateral boundary offset. The vehicle is aware of its position and attempts to re-enter the course as quickly as possible and will pick up the next waypoint as soon as it re-enters the bounds. Another issue is when the vehicle is found to be stuck. It can sense this through the use of different sensors. If we find the wheel speed to be greater than zero, while the vehicle speed is in fact zero, then we can determine that the vehicle is not moving as expected and take necessary steps to free the vehicle and continue on. Finally if an object is determined to be in the path of the vehicle using the sensor array, it will make the necessary steering and speed decisions to avoid the given object. This is why vehicle parameters and "awareness" of surroundings at all times is critical.

2.4.2 Methods for vehicle maneuvers

Our vehicle braking is set up using a motor and pulley system. Therefore, we can use small amounts of force on the pedal, or retract it very quickly to come to an immediate stop. When starting on a hill, the vehicle can sense the location of the pedals and will begin applying the gas as soon as the brake is released. Also, the vehicle is aware of the course boundaries since they look like obstacles. Therefore the vehicle makes necessary maneuvers to avoid going out of bounds, or hitting the obstacles. If it happens to get stopped because it cannot turn sharp enough to make a turn, it has the capability to backup and attempt to take the turn at a different angle.

2.4.3 Method for navigation and sensing Integration

Our systems are aware of an optimum path we would like to travel. Therefore the main controller attempts to match that path with the given sensor data. However, the vehicle will traverse a path that is as close to our optimum as possible when objects or terrain problems begin to become apparent.

2.4.4 Non-autonomous Vehicle Control

We have developed a wired communication device to control the truck. The device operates off of a standard Playstation 2 controller, but gives us the capability to control the vehicles gear, steering position, speed, and safety emergency stops (both a pause mode and a engine killed stop mode). This allows us to have full control of the vehicle including the ability to move the vehicle with all of our systems still in place.

Since actuation on the brake is performed from the rear of the pedal via a cable system, a driver can override the brake at any time by applying more pressure to the brake pedal. A human will need to use the wired controller to cause motion of the vehicle.

A driver can assume steering control by adjusting the tilt steering wheel that is found on the vehicle. A chain tensioned with the tilt steering function performs steering autonomously. By adjusting the tilt of the steering wheel, the tension on the chain is removed so it can be disengaged. Steering is then performed just as in a standard car, as the steering column has not been modified. However, a human may also steer the vehicle using the wired controller without removing the tension on the chain.

2.5 System Tests

2.5.1 Testing Strategy

The vehicle is tested weekly in varying off-road terrain. It is run in terrain similar to fields, paved and unpaved roads, and roads with dense foliage (surrounding, on, and over). We have also taken our vehicle to the JOUSTER course at VIR twice to see its interaction with an unfamiliar environment. We have tested in many differing temperature conditions from freezing weather to temperatures in excess of 110 degrees Fahrenheit. Weather has been a variable in our testing since outdoor testing has been run in sunny, rainy, wet, and muddy conditions. One more variable would be time of day, since conditions such as the suns position vary as the day proceeds. Our attempt is to see many different types of environments and conditions to test reliability and accuracy of our vehicle's decisions.

2.5.2 Test Results/Key Challenges

The test results were gained weekly through field-testing. Our attempt was to test our hardware and software in real world situations. This allowed us to use an iterative approach, by feeding our weekly results into our development cycle. This also brought out many issues that became apparent after running in real conditions and environments.

These testing sessions revealed many different challenges. Sensor update rates were critical and important, because decisions must be made very fast and these cannot be made validly without sufficient data rates. False positives are very tough to deal with because it can slow down the vehicle, or make it less confident in its steering and speed decisions. Sensor conflicts were an interesting issue because different sensors detect different types of obstacles and give different types of output and information. The environmental concerns including sun, rain, and dust quickly became apparent while testing. Sensor failure also became a challenge that needed to be dealt with.

Some challenges became apparent early in our development cycle and needed to be solved to proceed. An appropriate testing place was a challenging problem to solve. We were able to team up with North Carolina State University to use a large area of land with differing terrain. Then finally lack of funding was an extremely important and challenging issue that limited our ability to pursue aspects of the development we wanted to enhance. This lack of funding also limited our ability to test in desert terrain.